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WORK CREW OPTIMIZATION WITH SLAM II

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ABSTRACT

Resource allocation, such as labor, plants and machinery, is crucial in construction planning. Most construction projects are complex and thus, its planning requires network scheduling techniques. However, optimal result is rather difficult to obtain with so many variances for every different construction project. This study focuses in optimizing working crew for the floor element, especially in the construction of multi storey buildings, by means of simulation. Data on crew size and their working efficiency were collected through site observations which were further analyzed by using a simulation model, SLAM II. Results obtained from this study revealed the application of SLAM II in optimizing the allocation of labour in construction scheduling.

KEYWORDS: Simulation, SLAM II, Work Crew, Optimization, Typical Floor Schedule

INTRODUCTION

It is a critical task in scheduling the floor element as it involves a series of various trades such as placement of formwork and reinforcement followed by tedious casts of concrete and allowance for other trades such as electrical and plumbing. In multi storey buildings, floor is a massive repetitive element. Therefore, scheduling of floor element requires expertise to plan the proper amount of labour for a non disrupted execution of all the trades involved. In such complicated tasks, simulation tools can help the planner achieve construction optimization in a more feasible planning time. In this study, the number of workers and the man-hours required to work on the floors of a medium sized office building of reinforced concrete were recorded from site observation as input for simulation in SLAM II. Further simulation will help determine the optimum crew size for a typical floor construction.

PREVIOUS STUDIES

On work crew optimization in a construction project, various methods were developed and applied. For repeatable work scheduling, Halpin developed a resource distribution method named CYCLON which is widely used in construction simulation [1][2]. Shi proposed resource-based modeling (RBM) [3] and Activity-Based Construction (ABC) modeling [4]. AbouRizk et al. discussed on automating system optimization through simulation with CYCLONE, SLAMSYSTEM [5]. In computer simulation, easiness of modeling is crucial. Martinez et al. examined the characteristics of discrete-event simulation systems in terms of their application. The examined simulation systems were primarily CYCLONE and STROBOSCOPE [6].

OBJECTIVE AND SCOPE

Construction of reinforced concrete buildings and structures are complicated because it involves multiple trades which may appear idling to one another and this could resort to the decrease in efficiency [7][8]. To prevent such decrease in efficiency, it becomes important that the coordination between carpenter, re-bar placer and concreter are properly

scheduled and the number of workers optimally determined. Thus, this study is conducted to; (i) analyze working trades in the floor element, (ii) build a simulation model of the working trades in the floor element, (iii) use computer simulation to optimize number of workers for each trade in the floor element.

TARGET OF STUDY

A medium sized office building of reinforced concrete was selected for the purpose of this study, focusing only on the floor element. Table 1 depicts the outline of the project selected for this study. Figure 1 shows the typical floor plan and a sectional view of the said building. Conventional formwork of 12 mm thick plywood was used in the construction of this building. The total area of typical floors in this building is 2,322 m^2 with 41.66 tonnes of reinforcement and 246 m^3 of concrete.

Table 1: Outline of the Project

Item	Description
Building use	Office
Storey	Basement:1 storey Above the ground: 6 stories
Building area	614 m^2
Total floor area	4,332 m^2
Height	25.78 m
A Typical floor area	614 m^2
A Typical floor height	3.70 m

OBSERVATION OF WORK PROCESS AND MAN-HOURS

Observation on working trades was conducted to identify the sequence of activities in the construction of a typical floor. Man-hours for each activity were measured to obtain Unit requirement for that particular activity. Work sampling method was used to collect afore mentioned data with an observation interval of 5 minutes. To record on stable working condition, data collection commenced from 3rd to 6th floor where workers had become accustom to the working environment [9][10].

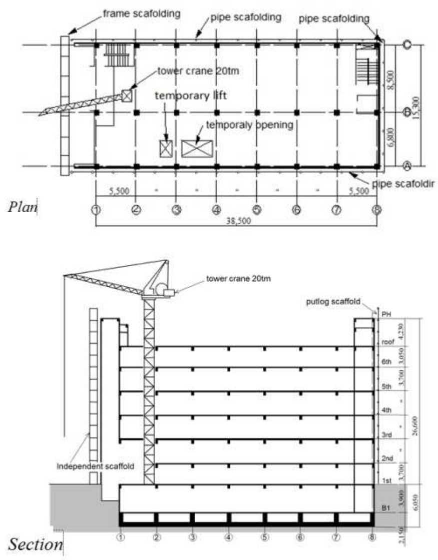

Figure 1: Plan and Sectional View of the Project

ACTIVITIES AND MAN-HOURS

Working Crew

From the observation on working activities and man-hours data recorded, an illustration in the fluctuation on the number of carpenters and rebar placers is shown in Figure 3. Activities are being illustrated in the form of network on the top part of Figure 3. The bottom part indicates the number of workers in a crew during the specified activity. Generally, there were more carpenters in a crew; ranges from 0-12, as compared to the number of re-bar benders in a crew, ranges from 0-5. From observation, the number of carpenters in a crew is most concentrated on day 10 and day 11 for the erection of slab formwork. Overall observation shows frequent fluctuation in the number of workers in a working crew for all activities.

Man-Hours

Man-hours were calculated by multiplying the number of workers in each activity by a 5 minute sampling interval. Then, man-hours per floor were determined in each activity. The results were shown in Table 2. The Unit requirement on erection of formwork was 0.36 to 0.92 man-hours/m^2, placement of reinforcement was 9.83 to 20.00 man-hours/tonne, re-bar jointing (pressure welding) was 0.16 to 0.18 man-hours/joint.

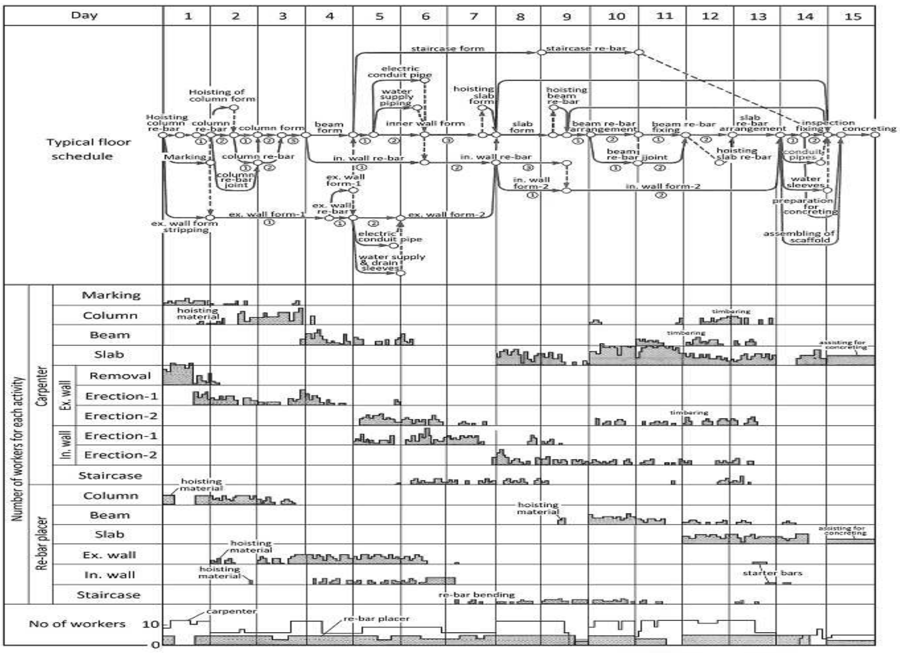

Figure 3: Number of Workers and Work Processes per Floor

MODELING THE WORK PROCESS

Elements Configured in the Model

With the results obtained through observation, the list of activities to be included in the simulation model is summarized in Table 3.

Building Simulation Model

In configuring the simulation model, Table 3 was used as the input for the element of activities. Added as resources was a crane to hoist materials. Thus, SLAM II model replicates the activities according to logical networking.

Figure 4 shows part of the simulation model. By setting the number of workers required for each activity, the simulation will indicate the number of workers required for the said activity to appear occupied upon commencement of that activity and at the end of that activity, the workers are released.

Table 2: Unit Requirement of Each Activity

Work	Activity	Unit requirement
Formwork	making	0.07 man-hours/m^2
	column form erection	0.79 man-hours/m^2
	beam form erection	0.77 man-hours/m^2
	slab form erection	0.36 man-hours/m^2
	exterior wall form erection	0.64 man-hours/m^2
	inner wall form erection	0.53 man-hours/m^2
	staircase form erection	0.92 man-hours/m^2
Reinforcement	column re-bar erection	9.83 man-hours/ tonne
	beam re-bar erection	10.86 man-hours/tonne
	slab re-bar erection	16.30 man-hours/tonne
	wall re-bar erection	15.67 man-hours/tonne
	staircase re-bar erection	20.00 man-hours/tonne
	column re-bar jointing	0.18 man-hours/joint
	beam re-bar jointing	0.16 man-hours/joint

Table 3: Trades and Activities in the Simulation Model

Work	Trade	Activity
Formwork	Carpenter	marking, form material hoisting, column erection, beam erection, exterior wall form stripping, exterior wall form erection-1, exterior wall form erection-2, inner wall form erection-1, inner wall form erection-2, staircase form erection, slab form erection, remaining work in slab form, timbering
Reinforcement	Re-bar placer	re-bar hoisting, column re-bar arrangement, column re-bar fixing, beam re-bar arrangement, beam re-bar fixing, exterior wall re-bar erection, inner wall re-bar erection, staircase re-bar erection
	Re-bar jointer	column re-bar jointing, beam re-bar jointing
Building services work	Electrician	electric conduit piping
	Plumber	sleeves for water supply & drainage pipes, sleeves for air conditioning duct
Concreting	Concreter	preparation of concreting, concreting

PARAMETER SETTING AND VALIDITY TEST OF THE SIMULATION MODEL

Unit Requirement and ITS Fluctuation

Unit requirement for formwork and reinforcement works were obtained from man-hours measurement taken by observation. Unit requirement for temporary works, building services and concreting were estimation with reference to the Civil

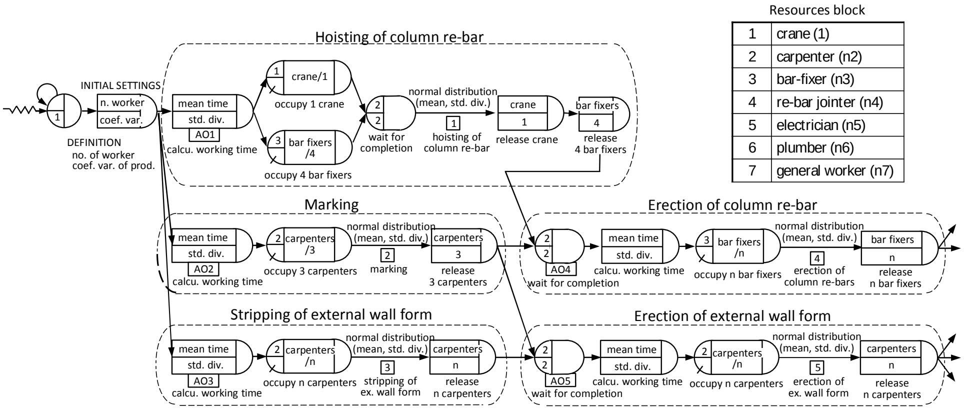

Figure 4: Simulation Model by SLAM II (Part)

Engineering Standard Productivity Handbook [11]. The coefficient of variation in Table 4 was used as fluctuation in Unit requirement. As indicated in Table 4, the values differ among activities within a range of 0.25 to 0.43. Unknown variables were assumed as similar to formwork, 0.35, which is a value close to the median of the said range.

Table 4: Coefficient of Variation of Productivity in Formwork

Activity	Coefficient of Variation
Marking	0.43
Column form erection	0.30
Beam form erection	0.31
Slab form erection	0.42
Exterior wall form erection	0.31
Inner wall form erection	0.25
Staircase form erection	0.42

Validity Test of Simulation Model

In examining the validity of created model, a pilot simulation was conducted under preset conditions and the results were compared with the simulation of the actual project. Items examined were, (i) number of workers in each activity, (ii) working duration per floor, and (iii) total man-hours per floor.

Figure 5 shows a comparison of the simulation results from the pilot data and the actual data on the number of workers for each activity. Figure 5 focuses on two primary trades: carpenter and re-bar placer. The number of workers shown from the simulation of the pilot data was almost similar to that of the actual project in both trades, except for minor activities such as material hoisting and timbering. As for the total man-hours per floor, Table 5 shows the result from the pilot data and the actual data. The ratio between pilot data and actual data were less than 3 percent. Thus, the simulation model is concluded as capable of accurately portraying an actual project.

OPTIMIZATION OF CREW SIZE

Relation between Number of Workers and Total Man-Hours

Figure 6 shows the relationship between number of workers and total man-hours. When the number of carpenters is 12 or more, total man-hours decreased as the number of re-bar placers increased from 3 to 7. When the number of carpenters is less than 12, it had an adverse effect on total man-hours with the increase on the number of re-bar placers, thus giving a concave curve which indicates an optimum combination on the number of workers for both trades for

minimum total man-hours possible. For example, to have 8 carpenters and 4 re-bar placers working together would complete the works at 3,090 man-hours, which would be the shortest duration possible. Also, if the number of carpenters is low, a minimum man-hour value exists when the number of re-bar placers is also low.

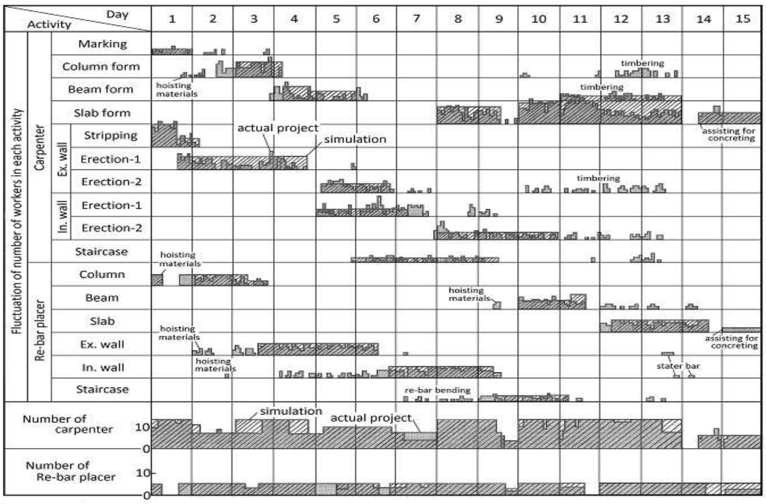

Figure 5: Comparison between Simulation and Actual Project

Minimizing Total Man-Hours

The relation between number of workers and the duration required per floor as shown in Figure 7 can be used to optimize the number of workers. Example of its application, to complete a floor in less than 18 days and only a maximum of 12 carpenters is available, the number of re-bar placers to allocate for minimum total man-hours by cross referencing Figure 6 and 7 would result in 5 re-bar placers with a total of 2,920 man-hours.

Table 5: Comparison between Simulation and Actual Project

Item	Simulation	Actual Project	Simulation / Actual Project
Duration per floor	15.4 days	15.0 days	1.03
Man-hour per floor	2,312 man-hours	2,358 man-hours	0.98

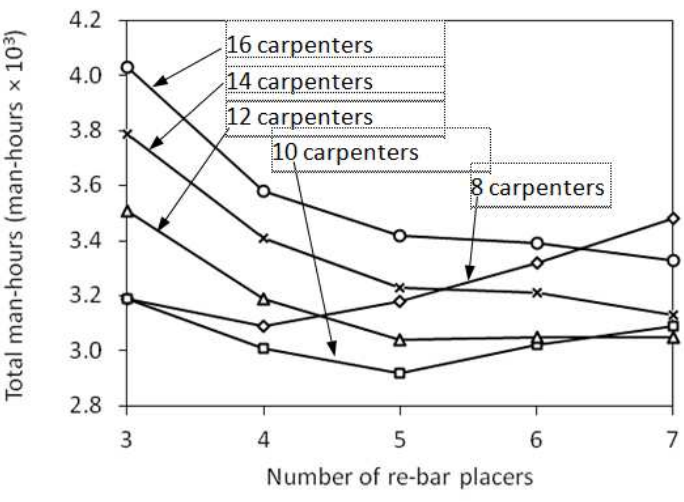

Figure 6: Relationship between the Number of Workers and Total Man-Hours

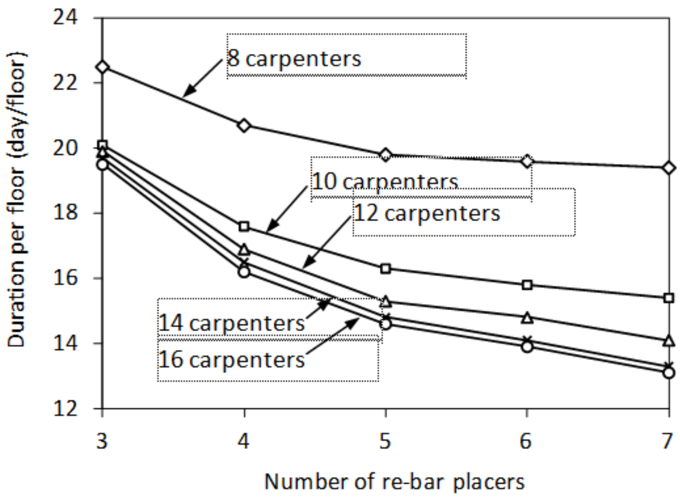

Figure 7: Relationship between Number of Workers and Duration per Floor

Minimizing Labour Costs

Labour costs calculation is only limited to carpenters, re-bar placers, re-bar jointers, electricians, plumbers and concreters. The relative labour unit cost (labour cost index) of each trade when the carpenter is 1.0 is shown in Table 6. The relation between number of workers and labour cost index are indicated in Figure 8. When there are no restrictions in duration, the optimum number of workers would be 10 carpenters and 5 re-bar placers with total labour cost index at 2,380 and a duration of 16.3 days by referring to Figure 7. Practically, duration is restricted and given for example, a time limitation of 15 days. By referring to Figure 7, the range of optimum combinations are (i) 12 carpenters with 6 or more re-bar placers, (ii) 14 carpenters with 5 or more re-bar placers and (iii) 16 carpenters with 5 or more re-bar placers. By referring to Figure 8, minimum cost index would confirm an allocation of 12 carpenters with 7 re-bar placers with the cost index of 2,490.

Table 6: Labour Cost Index for Each Trade

Trade	Labour Cost Index
Carpenter	1.00
Re-bar placer	0.70
Re-bar jointer	1.45
Electrician	0.80
Plumber	1.08
Concreter	0.60

Note 1): Labour cost indices were calculated based on the cost data in S company in 2012

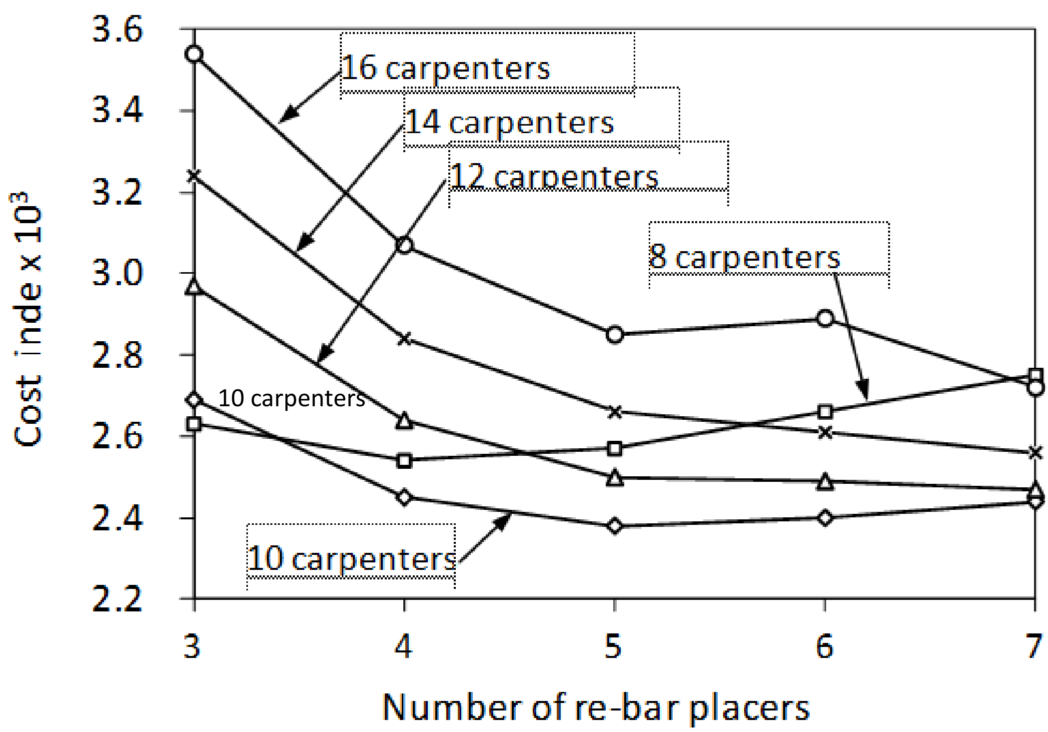

Figure 8: Relation between Number of Workers and Labour Cost Index

CONCLUSIONS

In this study, the application of SLAM II in modeling pilot simulation had shown very close resemblance to the output from actual observation of an ongoing project. With adequate and sufficient data, SLAM II is able to simulate the actual outcome of a project. By changing various factors, the simulation from SLAM II could provide useful information for construction planning such as resource allocation, especially labour, construction duration, total man-hours and labour costs. With afore mentioned information, optimization of crew size is made possible by identifying minimum man-hours and its minimum labour costs.

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